A CENTENNIAL REVIEW OF MAJOR LAND-FALLING TROPICAL CYCLONES IN SOUTHERN NEW ENGLAND

By David R. Vallee, National Oceanic and Atmospheric Administration / National Weather Service Forecast Office, Taunton, Massachusetts

Hurricanes and tropical storms are no strangers to Massachusetts. Forty-one such tropical cyclones have affected the region since 1900, 12 of which made landfall with significant impact. These 12 systems displayed similar characteristics with respect to the storm track for acceleration, high winds, storm surge, and heavy precipitation. This article reviews southern New England tropical cyclones since 1900, focusing on the similarities of these 12 land-falling systems as they impacted Massachusetts.

DATA SOURCES

Track information for each tropical cyclone was obtained from the National Climatic Data Center (NCDC) Historical Climatology Series 6-2 (NCDC 1993). Storm surge information was gathered through a collection of southern New England Hurricane Evacuation Studies produced by the U.S. Army Corps of Engineers. Rainfall analyses were obtained from prior publications (Vallee 1993, Vallee and Czephya 1996).

OVERVIEW OF THE 12 MAJOR LAND-FALLING TROPICAL CYCLONES

Table 1 shows the major tropical cyclones that have struck southern New England since 1900.

With the exception of the 1920s, Southern New England has experienced at least one major land-falling system in each decade of the 1900s (Figure 1). The 18-year period from 1938 to 1955 was quite active with five major systems, including four Category 3 hurricanes. The 15-year period from 1985 to 1999 was also active with four major systems, including two Category 2 hurricanes. Perhaps the most interesting statistic with regard to frequency is that since 1954, there have been no land-falling Category 3 hurricanes. August and September (Figure 2) were the most active months for tropical cyclone activity in Massachusetts, with 10 occurrences. The remaining two occurred in July.

TABLE 1 - TWELVE SIGNIFICANT TROPICAL CYCLONES IMPACTING SOUTHERN NEW ENGLAND, 1900-1999

Storm intensity at landfall is given by the Saffir / Simpson scale (see page 11) or listed as a tropical storm (TS). Forward motion is at time of landfall (miles per hour).

NAME	DATE	INTENSITY	FORWARD MOTION
Unnamed	7/21/1916	CAT 1	18
Unnamed	9/21/1938	CAT 3	51
Unnamed	9/14-15/1944	CAT 3	30
Carol	8/31/1954	CAT 3	40
Edna	9/11/1954	CAT 3	46
Diane	8/18-20/1955	TS	15
Donna	9/12/1960	CAT 2	25
Belle	8/9-10/1976	CAT 1	20
Gloria	9/27/1985	CAT 2	45
Bob	8/19/1991	CAT 2	30
Bertha	7/12-13/1996	TS	30
Floyd	9/18/1999	TS	35

COMMON CHARACTERISTICS OF THE 12 LAND-FALLING TROPICAL CYCLONES

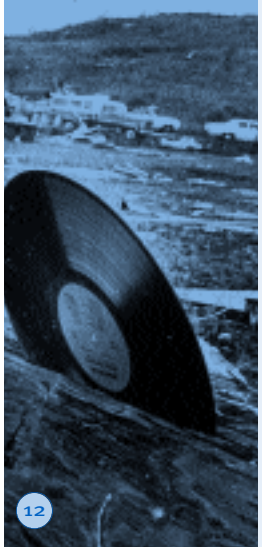
Each of these 12 systems, with varying degrees of impact, brought high winds, coastal flooding, and heavy precipitation to the region. Each system experienced some degree of forward acceleration. The core of strongest winds and the largest storm surges were always focused east of the storm track. The heaviest precipitation was always focused along and west of the storm track.

Forward Motion

Each system displayed significant northward acceleration. The average forward speed at time of landfall was 33 miles per hour (mph), while 51 mph was observed with the Great New England Hurricane of 1938. The rapid acceleration enhanced high winds, storm surge, and heavy precipitation.

Wind

The rapid acceleration of these systems produced a rather short duration of both tropical storm and hurricane force winds, when compared to slower moving tropical cyclones elsewhere in the western Atlantic. The average duration of tropical storm force winds ranged from 12 to 15 hours. Hurricane force winds were generally produced for three to six hours centered around the time of landfall. Systems accelerating up the coast were often imbedded in deep layer southerly flow. In the Northern



Hemisphere, the components of surface wind and the mean flow act in the same direction, producing enhancement (Elseberry et al. 1987). Also, as this acceleration occurs, the eye diameter expands, causing an eastward displacement of the radius of maximum wind (RMW). This pattern was observed in Hurricane Bob, with a RMW of approximately 25 miles (National Weather Service 1992), and in the Great New England Hurricane of 1938 with a RMW of over 40 miles.

As a crude rule of thumb, an area due to experience this core of sustained winds can add the forward motion to the sustained wind speed. This sum gives an estimate of the maximum gust potential. In 1938, for example, the Great New England Hurricane of 1938 was moving rapidly north near 60 mph, producing sustained winds of 125 mph. Adding the forward motion to this sustained wind speed gives an estimated maximum gust potential of 185 mph. The Blue Hill Observatory, in Milton, Massachusetts, recorded a wind gust of 186 mph.

Storm Surge

The rapid acceleration impacts the magnitude of the storm surge. Wind stress and pressure gradient are the key components in surge production, with wind stress accounting for approximately twice the surge produced solely by pressure gradient (Anthes 1982). The angle at which the systems made landfall in Massachusetts was generally 60 to 90 degrees, or close to perpendicular to the coastline, aiding in surge production on north-south oriented bays and inlets.

While the stronger tropical storms produced surges of 1 to 3 feet, the Category 2 and Category 3 storms generated storm surges in excess of 12 feet. For the two most powerful storms, the Great New England Hurricane of 1938 and Hurricane Carol in 1954, the RMW was focused on eastern Connecticut and Narragansett Bay. Surge modeling indicates that for a storm similar to Hurricane Carol but focused on the South Coast of Massachusetts surges in excess 25 feet will occur on portions of Buzzards Bay (U.S. Army Corps of Engineers 1997).

Most of east coastal Massachusetts is quite vulnerable to storm surges, but due to the rapid movement of hurricanes, the tidal piling most often associated with major coastal flood episodes in the wintertime on the east coast doesn't have time to materialize. Slosh modeling suggests that a surge of 4 to 7 feet is possible in and around Boston Harbor. If this struck on a high astronomical tide, the resulting tidal elevations could surpass those produced by the October 1991 storm and the Blizzard of 1978. But it would take a unique sequence of events for such a surge to materialize—unlike along the exposed south coast where there is far greater potential and frequency of occurrence.

The uniqueness of Cape Cod Bay provides a different problem. Hurricane Edna of 1954 provided nearly the optimum set of circumstances to produce a surge of 10 feet across Wellfleet and Truro. For this to occur, the storm had to travel directly over the top of Cape Cod. The northeast wind flow ahead of this type of storm track would pile the water into Cape Cod Bay. Then approximately 1 to $1^{1}/_{2}$ hours after the storm has passed, a wind shift to the southwest will literally slosh the water around the base of the bay into Wellfleet and Truro. Researchers believe that this did occur with Edna, but her arrival at low tide spared the region significant flooding.

Rainfall

Nearly half of all tropical cyclones that have impacted southern New England since 1900 produced significant river and small stream flooding. Heavy rainfall typically developed well in advance of the storm center, in response to the dramatic increase in moisture advection and a rapidly destabilizing atmosphere produced by a deepening upper level trough or cut-off low. In addition, as shown by Vallee and Czephya (1996), strong east or southeast inflow produced an enhancement of rainfall in upslope regions of the major river basins in the region. The duration and strength of this inflow was critical to the magnitude of the enhancement. Tropical cyclones tended to maximize both components, thus explaining why, in spite of such a rapid forward motion, tropical cyclones impacting southern New England also produced widespread torrential rainfall.

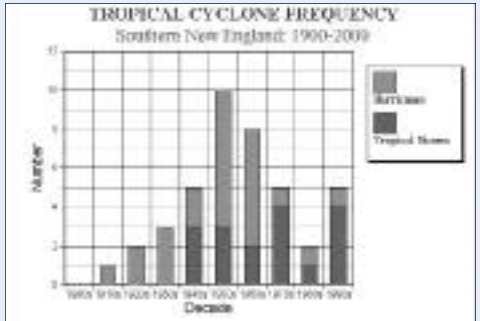


FIGURE 1: TROPICAL CYCLONE FREQUENCY IN SOUTHERN NEW ENGLAND

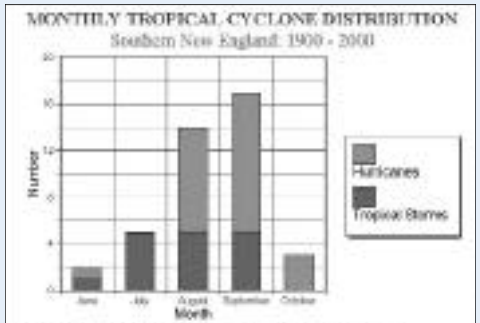


FIGURE 2: MONTHLY TROPICAL CYCLONE DISTRIBUTION FOR SOUTHERN NEW ENGLAND

Typically, the first bands of heavy rainfall arrived 12 to 15 hours in advance of the storm center. The average rainfall of 6 to 10 inches was west of the track of the storm, with the heaviest amounts in topographically enhanced locations. East of the storm, two inches or less was common. Hurricane Bob, a tight Bahama-born system, produced a dramatic rainfall distribution across Rhode Island with a maximum of more than 7 inches in the northwest and less than 0.5 inches in nearby southeast Massachusetts.

One of the most dramatic displays of heavy rainfall was associated with Tropical Storm Diane, August 1955. One week prior to Diane, a very weakened Tropical Storm Connie sent 4 to 8 inches of rain across western Massachusetts. Then, just 5 days later, Diane would produce 10 to 20 inches of rain in a 2-day span across much of the Bay State. In Westfield, Massachusetts, Diane produced a record one-day rainfall total of 18.15 inches; to put this in the proper perspective, that was nearly half their annual rainfall!

CONCLUSION

Major land-falling tropical cyclones in southern New England during the last 100 years have all displayed similar characteristics. This consistency in behavior should allow forecasters and emergency managers to better anticipate and prepare for the evolution of the storm's impact across the region.

REFERENCES

Anthes, R. A., 1982: *Tropical Cyclones, Their Evolution, Structure, and Effects*. Science Press, 208 pp.

Elseberry, R. L., W. M. Frank, G. J. Holland, J. D. Jarrell, R. L. Southern, 1987: *A Global View of Tropical Cyclone. Office of Naval Research*, 185 pp.

National Climatic Data Center, 1993: *Tropical Cyclones of the North Atlantic, 1971-1992*. NOAA Historical Climatology Series 6-2, Asheville, NC, 193 pp.

National Weather Service, 1992: *Disaster survey report - Hurricane Bob August 16-20, 1991*. NOAA, U.S. Dept. of Commerce, 57 pp.

U.S. Army Corps of Engineers, New England Division, 1997: *Southern Massachusetts Hurricane Evacuation Study*. USACE Technical Data Report, Waltham, MA, 100 pp.

Vallee, D. R., 1993: *Rhode Island Hurricanes and Tropical Storms, A Fifty-Six Year Summary 1936-1991*. NOAA Tech. Memo. NWS-ER-86, Bohemia, NY, 62 pp.

_____, and L. Czephya, 1996: *An Analysis of Orographically Induced Rainfall in Southern New England*. Preprints, Fifteenth Conference on Weather and Forecasting (Norfolk), American Meteorological Society, Boston, 269-271.

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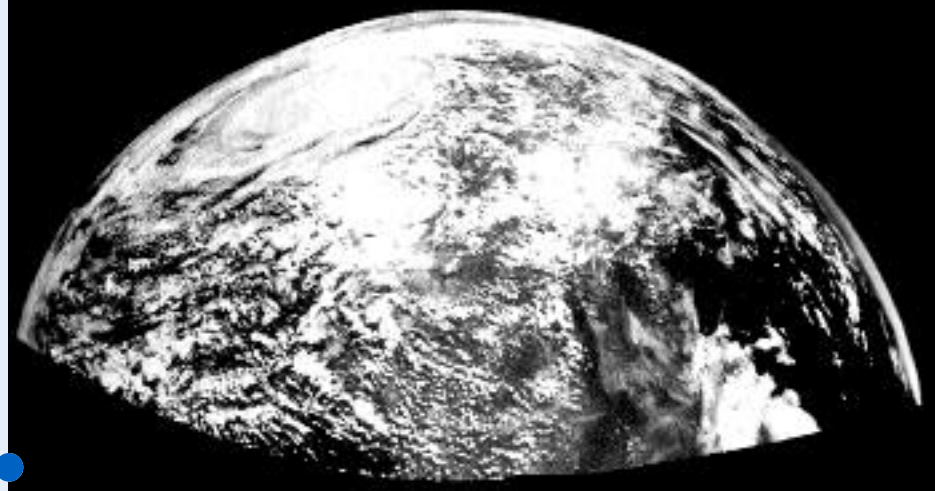

SATELLITE VIEW OF TROPICAL CYCLONE NEAR DEL RIO, TEXAS, OCTOBER 5, 1954.

photo courtesy of NOAA